

N93-13186

Preparing Safety Data Packages for Experimenters Using the Get Away
Special (GAS) Carrier System

by

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ABSTRACT: The implementation of NSTS 1700.7B and more forceful scrutiny of data packages by the Johnson Space Flight Center (JSC) lead to the development of a classification policy for GAS/CAP payloads. The purpose of this policy is to classify experiments using the carrier system so that they receive an appropriate level of JSC review (i.e. one or multi-phase reviews). This policy is based on energy containment to show inherent payload safety. It impacts the approach to performing hazard analyses and the nature of the data package. This paper endeavors to explain the impact of this policy as well as the impact of recent JSC as well as Kennedy Space Flight Center (KSC) "interpretations" of existing requirements.

The GAS canister does adequately contain most experiments when flown in the sealed configuration (however this must be shown, not merely stated). This paper also includes data package preparation guidelines for those experiments that require an opening door which often present unique safety issues.

INTRODUCTION

The GAS carrier system was originally intended to fly inherently safe experiments in a sealed canister that provided an adequate level of containment. As additional carrier system features were acquired (e.g. opening doors and ejection systems) and more dangerous experiments were accepted in the program the assumption of inherent safety became questionable. Moreover a new program, CAP (Complex Autonomous Payloads), was recently introduced. CAP payloads also use the GAS carrier system but are manifested as secondary Space Transportation System (STS) payloads whereas GAS payloads are tertiary payloads of flight opportunity. Although programmatically distinct the carrier system hardware is identical. The implementation of the CAP program, the acquisition of additional carrier system capabilities, and the visibility of increasingly dangerous experiments lead to a reassessment of the manner in which Safety Data Packages (SDPs) are processed at the Goddard Space Flight Center (GSFC) and JSC. The implementation of a new policy classifies payloads for inherent danger and directly relates to the logic of hazard analyses and the manner in which SDPs are prepared.

BACKGROUND

GSFC had routinely processed GAS payloads in accordance with mutual agreements among the centers that were forged years ago at the inception of the GAS program. The purpose of these agreements or understandings was to simplify the processing of payloads and the development of all documentation related to flight approval. The nature of these agreements considered the inherent danger of the user's hardware/operations within the context of the standard carrier system which provides containment by the canister as a fundamental and incontrovertible hazard control. Unfortunately, these agreements were never formally documented and over the years as the experiments became more complex and the carrier system acquired additional features, the "ground rules" became more and more subject to interpretation. In the recent past these interpretations have differed significantly and the distinction between design "guidelines" versus design requirements has become muddled even though the original GAS concept (i.e. inherent safety by containment) remains consistent for a majority of the payloads flown.

The purpose of the classification scheme for payloads utilizing the GAS carrier system is to determine the appropriate level of JSC scrutiny in the phased safety review process based only upon the inherent danger posed to the Orbiter or its crew by the payload regardless of programmatic considerations. An overview of the carrier system, the initial safety review process, and the approach for classifying and reviewing GAS/CAP payloads is presented below.

CARRIER SYSTEM OVERVIEW

The basic GAS carrier system is comprised of either a 5 or 2.5 cu ft. canister that is mounted to either an adapter beam in the cargo bay or to the GAS bridge structure which straddles the cargo bay. Each beam can accommodate 2 canisters whereas the bridge can carry up to 12 GAS canisters. Additionally, each canister configuration can vary depending upon the needs of the experiment that is contained in the canister. However, the majority of GAS/CAP payloads utilize the most basic configuration which is the sealed canister with no intentional venting and an inerted (i.e. no oxidizers present) internal atmosphere at 1 atm. The bridge, adapter beams, associated mounting hardware, as well as the canisters and the canister components are reflight hardware that is systematically tracked and refurbished or replaced in accordance with procedures approved by JSC.

The canister itself is made of two 0.625 in. thick aluminium end plates mounted to opposing ends of a 0.125 in. thick aluminium cylinder. The canister design has been verified by proof pressure testing to 115 psig. The basic canister configuration includes two pressure relief valves in the bottom endplate set at 30 and 45 psid. After the experiment is integrated into the canister and the endplates are mounted, the canister is leak checked and later backfilled with dry nitrogen prior to launch.

The fundamental premise of the basic carrier system configuration is the control of hazards via containment. In the case of solids (e.g. failed structure) it has been shown by analysis that the canister will contain

any failed structure up to 200 lbs. (which is the weight constraint for GAS/CAP payloads) under all possible STS loading conditions. This analysis has been reviewed and approved by JSC. There are only 2 constraints for payloads related to structures: the Center of Gravity (CG) envelope which is virtually impossible to violate, and the requirement that the payload's fundamental frequency be greater than 35 Hz. These requirements relate to the attachment points of the can to either a beam or the bridge and not directly to the hardware sealed inside the canister.

The fact that the canister has been shown to contain failed experiment support structure does not obviate the need for a structural analysis of the experiment as such an incident would damage the GAS avionics and associated equipment. Furthermore, the analysis pertains only to unaccelerated debris and does not envelope dynamic situations (e.g. exploding pressure systems).

As mentioned above the canister is leak tested, post-payload integration and prior to launch which, in GSFC's view, confirms the asserted control of primary containment for fluids as long as the fluid is compatible with the canister and does not degrade the endplate or relief valve seals. Material usage in the canister is reviewed and approved by the GSFC Material Branch for the purpose of compatibility with the particular application.

The GAS carrier system may also be configured to vent through the endplate on ascent via a filtered port or through a check valve (in the former the canister repressurizes upon reentry while in the latter it lands at vacuum). Any portion of the canister or any sealed container within the canister may be vented to space through one of the purge ports. The canister may be equipped with a Standard Door Assembly (SDA) which can be opened on - orbit exposing the experiment to space. Additionally, an ejection system to launch small satellites has been developed and been approved by JSC as have the SDA.

There are two other hardware options available to the GAS carrier user. Each canister may be equipped with a redundant battery vent system that is used to vent a sealed battery box outside of the canister through filtered pressure relief valves set at 15 psid. This option is highly recommended and frequently used as a control for the potential of accumulating gases from discharging batteries inside the canister. The other option is a baroswitch which can be used to turn the payload on/off at a predetermined altitude during ascent/descent. Ordinarily the payload is turned on/off by the crew via the APC (Autonomous Payload Controller) in the cabin.

INITIAL GAS/CAP SAFETY REVIEW PROCESS

By mutual agreement GSFC conducts what is analogous to the Phase 0, I, and II Safety Reviews. This process is often multi-iterative involving the user and GSFC personnel from the Special Payloads Division (code 740) and the System Safety Branch (code 302). When necessary specialized experts are available and consulted for specific issues (e.g. electrical, thermal, mechanical). Each Payload Organization (PO) is

required to submit a materials list which is reviewed by the GSFC Materials Branch (Code 313) and a structural analysis which is reviewed by a Code 740 contractor. The PO is also required to submit a Preliminary, a Final, and a Phase III Safety Data Package in accordance with certain milestones in the payload processing timeline. GSFC acts essentially as a surrogate safety review panel for all but the ultimate Phase III SDP which is submitted to JSC (1).

The review critique by GSFC considers the configuration of the carrier system as well as that of the contained hardware. The original concept of GAS was safety via containment as described above in the overview. The majority of GAS payloads are in the truly sealed configuration; they do not vent and they do not have SDAs. This concept of containment seems to have been lost in recent times at both GSFC and JSC. The logic of requiring a fuse on two seriesed "AA" alkaline battery cells inside a sealed canister made of 0.125" thick aluminum with 0.625" endplates that has been proof tested to 115 psig is not apparent.

There are some GAS payloads for which the containment argument is not true and the review logic is accordingly adjusted. For example, in a vented or MDA canister two "AA" cells could represent a viable ignition source which would need some kind of circuit protection or environmental isolation. The absence of the containment control gives rise to more potential hazards in terms of possibilities and magnitude.

Until the classification scheme was adopted there was no systematic approach to evaluate the inherent risk that the payload poses within the context of the carrier system in its various configurations.

CLASSIFICATION OF PAYLOADS USING THE GAS CARRIER SYSTEM

The classification strategy is based upon the degree of containment offered by the carrier system which depends upon the characteristics of the user's payload as well as the configuration of the carrier system.

Structures/Fluid Containment Properties

A properly assembled GAS canister has been shown by analysis to be capable of containing fractured structure weighing up to 200 lbs. which is the maximum mass allowed by GSFC. The proper assembly of the canister at the launch site is assured by following standard assembly procedures performed by GSFC field operations personnel.

Beyond the containment control for failed structure the structural integrity of the user's hardware is designed and verified to margins of safety in excess of those required for STS payloads. This is imposed by GSFC for although failed structure inside the canister would not pose a threat to the Orbiter it most likely would damage the carrier system hardware.

In a truly sealed GAS canister primary fluid containment is also verified in the field by a leak test of the canister in accordance with the standard assembly procedures.

Energy Containment Properties

The sealed GAS canister is capable of fully containing a limited amount of energy that may be released by the enclosed system. Additionally, it is also capable of releasing energy to the ambient environment in a controlled fashion via the pressure relief valves and by the passive thermal control system. The amount of stored energy used to operate the payload inside the canister is known and limited. For the most part, energy is in the form of potential energy that is chemically stored in the battery pack, however other devices such as pressure vessels are also to be considered in the analysis.

The rate at which the contained payload can release this energy depends upon the characteristics of the possible processes that can transform the stored energy of the payload into other dissipative forms of energy (heat, kinetic, and rf energy).

For example, all of the energy in the battery could be dissipated over a short period of time as heat via a dead short across its terminals resulting in a temperature rise of the battery. There is also the potential outgassing of combustibles from the battery. Some of the generated heat would cause an increase in the temperature and pressure in the canister but, this value can be calculated and compared to the canister pressure containment tolerance.

In the above example a dead short of a battery was assumed for the purpose of illustrating the concept. Batteries are particularly important devices as they provide all of the power to run the payload. It is not the intent of this approach to compromise prudent battery design features such as fusing the primary battery pack to prevent dead shorts. However, the need for fusing very low energy batteries in innocuous applications (e.g. flash bulbs, clocks, and memory backup) in sealed and inerted canisters is questionable and is evaluated in the context of energy containment.

Alternatively, the payload may contain a sealed fluid system or pressure vessel. If all of the battery energy is consumed by heating the fluid which overpressurizes the system then the energy may be released instantaneously depending upon the fracture mechanics of the fluid system. However, the amount of energy that can be released is known and limited. Again, if it can be shown that the instantaneous release of energy is the worst possible case and that the canister contains it or dissipates it in a controlled manner, we see no hazard to the Orbiter.

The canister is equipped with one filtered relief valve set at 30 psi and an unfiltered relief valve set at 45 psi (the canister has been proof tested to 115 psi) that provide accelerated pressure relief. As long as it can be shown that the rate of the pressure increase is less than the venting capacity of the pressure relief system and that the vented fluid is not intrinsically hazardous or incompatible with the Orbiter bay environment in any phase of the mission, we see no hazard to the Orbiter.

With respect to RF energy release the truly sealed canister has been shown to exhibit 70 db attenuation. Nevertheless all payloads that have significant EMI sources are required to show compliance with the STS ICD.

GSFC proposed that truly sealed GAS canisters in the most basic standard configuration as described above, and whose energy containment capabilities and materials compatibility are satisfactorily demonstrated be classified as class "B" (for benign) GAS/CAP payloads. The analysis of energy containment will be included in the SDP and will demonstrate containment in the worst case energy dissipation scenario possible and will evaluate the margin of the analysis.

GSFC also proposed that SDA payloads with no batteries (essentially exposure experiments) be included in the class B category. The structures hazard report will include fracture control requirements compliance.

GAS/CAP payloads that do not meet the criteria described above will be classified as "C" (for controlled) GAS/CAP payloads. These payloads will include ejectables and most of the other SDA canisters as well as some canisters that are not truly sealed (i.e. vent in part or in whole on ascent).

It must be recognized that the energy containment analysis is not a trivial exercise. It will involve an analysis of all energy storing devices (i.e. batteries, pressure vessels, chemical reactions, springs, flywheels, etc.) and the possible ways in which that energy can be transformed, possibly accumulated, and released. The intent of the modeling effort used to evaluate energy containment will initially be simplistic but may have to be refined to more accurately reflect the system if necessary. For example, assuming that all of the stored energy is consumed in an adiabatic process which raises the temperature (and pressure) of the nitrogen is a theoretical upper bound but in most instances it does not represent a process that is physically possible. However, if such a calculation confirms containment then there is no need for a more sophisticated model, otherwise the model will be refined.

This may sometimes involve complex thermodynamic analyses including transient multi-media heat transfer problems as well as other processes that are characteristic of the system and its environment.

SAFETY REVIEW PROCESSING

GSFC and JSC have determined that class B payloads be processed in much the same manner as most GAS/CAP payloads were initially processed. The only submittal to JSC will be the Phase III data package which can be processed "off line" without the need for a formal "face-to-face" review with the panel, however GSFC will support a formal review if deemed necessary by JSC. In short, return to the original concept of GAS payloads being considered as benign ballast.

When containment, as defined above, cannot be shown analytically (Class C) or when the margin of safety is questionable GSFC will issue a Phase 0/I SDP submittal with an option for a formal "face-to face" review. The second and third submittals will be the Phase II and III SDPs (or a combined Phase 2/3 if mutually agreed to) for which there will be a standard STS safety review.

THE SAFETY DATA PACKAGE

Much of this paper has been dedicated to defining the JSC/GSFC policy on safety reviews while foregoing any discussion as to its impact on the data package itself. Simply, the new policy is significant, yet minimal. All data packages should contain the information in a format as adeptly described by Gum. Compliance with JSC 13830B and NSTS 1700.7B must be shown. The minimal impact is the required inclusion of the containment analysis, particularly energy containment, in the safety assessment section of the document.

This analysis must show whether or not the payload is Class "B" for benign or "C" for controlled. In the former case it is acceptable to include information regarding system controls that limit certain experimental parameters (e.g. thermostats on heaters) within the descriptive narrative of the experiment. However, it should be emphasized throughout the document and especially in the safety assessment that such devices relate only to mission success and are not hazard controls. The class "B" payload, by definition, assumes total loss of all controls with no safety consequences. This must be shown not just merely asserted. It is anticipated that such payloads will have a minimum of 2 hazard reports: one for structural failure and one for asserting energy containment as described above. In some cases it may be necessary to include others (e.g. secondary fluid containment or batteries).

The SDP for the class "C" payload must show that hazard controls are either single or dual fault tolerant as appropriate pursuant to the criteria in NSTS 1700.7B. The proper approach in preparing a SDP is to perform a hazard analysis to determine if there are any hazards. If found, the level of control is defined by assessing the potential magnitude (i.e. Catastrophic or Critical) of the hazard. It is inappropriate and unacceptable to forgo the hazard analysis and arbitrarily include hazard controls in experimental designs. This applies to all "B" and "C" class payloads.

Beyond the technical requirements and results of analyses/tests the SDP must be clear and concise. It must be appreciated that the JSC review is usually conducted off-line so that there is no real time dialogue among GSFC and JSC during the evaluation of the SDP. The SDP must accurately and unambiguously describe the experiment, how it works, what the hazards (if any) are and how they are controlled.

References

- 1) Gum, M. "STS Safety Approval Process for Small Self Contained Payloads", GAS Experimenter's Symposium (Proceedings) 1988
- 2) JSC 13830B "Implementation Procedure for STS Payloads System Safety Requirements"
- 3) NSTS 1700.7B "Safety Policy and Requirements for Payloads Using the Space Transportation System"
- 4) KHB 1700.7 "STS Payload Ground Safety Handbook"